

Large-Scale Physical Forcing of Thin Layer Dynamics

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LONG-TERM GOAL

Our long-term goal is to understand how physical mechanisms influence the formation, maintenance and dispersion of thin biological layers. This understanding will help us to predict the frequency and occurrence of thin layers, and to identify other coastal regions that are favorable for thin layer development.

OBJECTIVES

Our major objectives were the following; (1) to complete the analysis of the physical data from the '1998 Circulation Study' (24 May - 2 June), the '1998 Thin Layers Experiment' (10 – 25 June), and data supporting the 'NRL hyperspectral overflight' (continuous data 24 May to 8 August 1998) in conjunction with optical and acoustical data from the same experiments, (2) to utilize our master statistical database to investigate the impacts of physical forcing on thin layer dynamics, (3) to

complete manuscripts from this work, and (4) to continue to make the physical data available to the oceanographic community.

APPROACH

A series of interdisciplinary cruises conducted in East Sound, WA in 1996 and 1998 provided a unique data set to address the mechanisms controlling thin layer dynamics. In 1996 these cruises were conducted to test new instruments and deployment techniques needed to simultaneously quantify optical and acoustical thin layers and the physical and biological processes that control them. ONR Biological & Chemical Oceanography and NSF Instrumentation grants to Dr. Donaghay supported these cruises. ONR Physical Oceanography has subsequently provided funds to Drs. Dekshenieks, Donaghay and Osborn for analysis of the physical mechanisms controlling thin layers based on the 1996 data. In 1998 ONR Biological & Chemical Oceanography and ONR Physical Oceanography supported a larger interdisciplinary experiment that included the '1998 Circulation Study' and the '1998 Thin Layers Experiment'.

Our three-step approach for this project has been completed. These steps are detailed in the 'WORK COMPLETED' section: (1) data processing; (2) expanding the master statistical database; and (3) data synthesis and manuscript preparation.

WORK COMPLETED

(1) Data Processing:

<u>DATA SOURCE</u>	<u>DESCRIPTION</u>	<u>STATUS</u>
Instrument Array: Autonomous Underwater Winch		
ctd (level 1)	data extracted	complete
ctd (level 2)	numerical programs applied	complete
optical (level 1)	data extracted	complete
optical (level 2)	apply correct calibrations	complete
	apply corrections for fouling	complete
data merge	merge ctd and optical data	complete
Instrument Array: ADCP		
current fields	current magnitude and direction from four 300 kHz and one 1500 kHz bottom-mounted ADCPs have been correctly surface referenced	complete
Ship-Based: High Resolution Profiler		
ctd data	numerical programs applied	complete
optical data	correct calibrations applied	complete
data merge	merge ctd and optical data	complete
Ship-Based: ADCP		
current fields	transects made with the ADCP have been reconstructed for visualization	complete
Supporting Data		
wave-tide gauge	tide data	complete

The physical data has been distributed to all researchers involved in the ‘Thin Layers Program’. In addition, the physical data has been made available to the oceanographic community by request.

(2) Expanding the master statistical database: The master statistical database contains information regarding the biological properties of each individual optical layer encountered during the 1996 and 1998 cruises. The database also contains salinity, temperature, density, Buoyancy frequency, shear and Richardson number which were calculated from physical measurements at the exact location of each thin layer. In addition, wind speed and direction, tidal information and the spatial relationship of the optical thin layer to the pycnocline are also recorded. The master statistical database, which now includes ship-based information, has been expanded to include data from the autonomous underwater winch profiler in the instrument array.

(3) Data synthesis and manuscript preparation: In addition to expanding our existing master statistical database, we have worked closely with other PIs in the ‘Thin Layers Program’ (specifically; Dr. Alldredge, Dr. Case, Dr. Cowles, Dr. Gifford, Dr. Holliday, Dr. MacIntyre, Dr. Perry, Dr. Rines, Dr. Smith, Dr. Weidemann and Dr. Zaneveld) to synthesize data and to develop several interdisciplinary manuscripts addressing thin layer dynamics. These manuscripts are listed in the ‘PUBLICATIONS’ section of this report.

RESULTS

Our results show that local hydrography plays a critical role in determining the spatial distribution, location (depth) and structure (thickness) of thin optical layers. In East Sound 71% of all thin layers were located at the pycnocline (between the wind forced surface layer and the tidally influenced sub-surface layer). Of the remaining 29% of the thin layers sampled, roughly 14% were below the pycnocline. These layers were frequently associated with advective processes within the system. The final 15% of the thin layers were sampled at times when density increased slowly and uniformly with depth, thus the pycnocline was not well defined. Buoyancy frequency, shear and Richardson number were calculated from physical measurements made at the exact location of each thin layer. Calculations show that thin layers occurred over a range of buoyancy frequencies. Buoyancy frequency is a variable commonly used to indicate the strength of the density gradient in the water column. Roughly 40% of all thin layers were in regions of the water column where the buoyancy frequency was relatively low (less than $0.0005 \text{ (rads/s)}^2$), while 60% of all thin layers were in regions of the water column with buoyancy frequencies greater than $0.0005 \text{ (rads/s)}^2$. The layers in the regions of higher buoyancy frequency were most often associated with the pycnocline. Calculations also show that thin layers occurred over a range of shear. There were two modes of distribution in the shear histogram. The first mode occurred at relatively low shear between 0 and $0.025 \text{ (s}^{-1}\text{)}$ and the second mode occurred at moderate shear between 0.025 and $0.05 \text{ (s}^{-1}\text{)}$. Only 5% of all thin layers were in regions of shear above $0.05 \text{ (s}^{-1}\text{)}$. Finally, the Richardson number, which is the ratio of the buoyant restoring force to the shearing force, was calculated. Results show that no layers were found in regions where the Richardson number was less than 0.23. In general, regions of the water column where the Richardson number is below a value of 0.25 are unstable, and thus, would not be able to support thin layer development (Dekshenieks et al in press, Rines et al in press).

Our results also show that regional-scale circulation patterns (e.g. buoyant plumes, episodic changes in water mass type) can have significant impacts on thin layer distribution. In East Sound, the water

masses change over time. These water masses result from the mixing of warm, low salinity (low sigma-t) water characteristic of the Strait of Georgia with cool, high salinity (high sigma-t) water characteristic of the Strait of Juan de Fuca (Redfield 1950). Several days prior to the 48 hour period depicted in Figure 1, a warm, low salinity (low sigma-t) water mass was advected into East Sound. Following a residence time of four days, this water mass was gradually advected out of the Sound at the surface in response to the wind. At the same time, cool, high salinity (high sigma-t) water characteristic of the Strait of Juan de Fuca was advected into the Sound below the wind forced surface layer. This produced the appearance of a gradual shoaling of the pycnocline. The vertical distribution of all thin layers (e.g. phytoplankton, zooplankton, bacterial production, marine snow and bioluminescence) also shoaled in response to the change of water mass type and the resultant shoaling of the pycnocline. The depth of thin layers is obviously highly dependent upon both local hydrography and episodic changes in water mass type driven by regional wind and tidal forcing (Dekshenieks et al in prep).

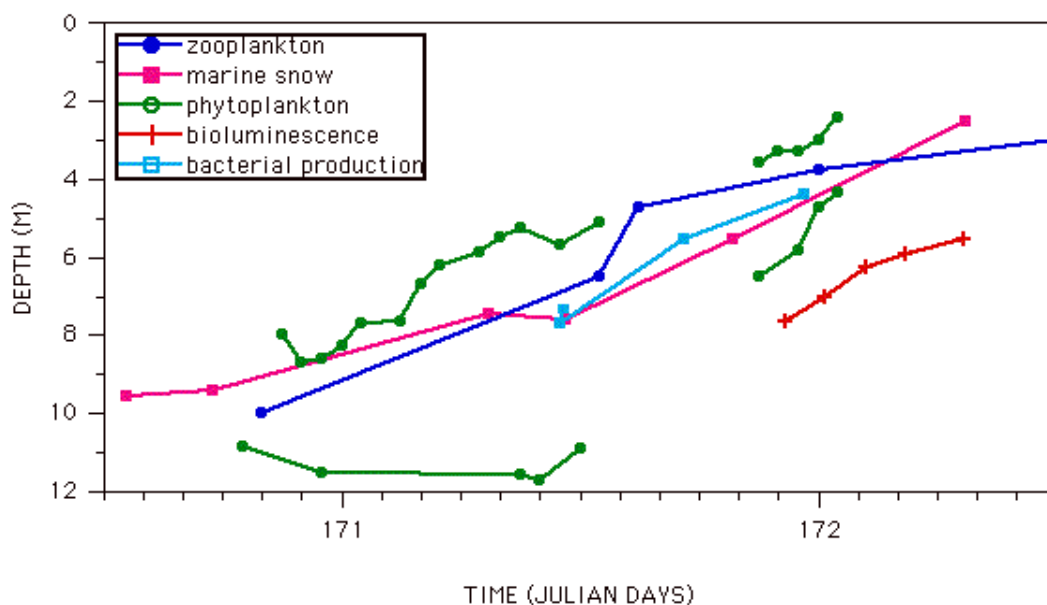


Figure 1: The depth of the maximum concentrations of total small zooplankton biovolume, marine snow, total absorption at a wavelength of 440, bioluminescence, and bacterial production, all vs. time.

IMPACT/APPLICATIONS

This research provides PIs in the 'Thin Layers Program' with a larger context of physical circulation, within which the finescale and microscale biological and physical processes that control thin layer dynamics may be addressed. It is clear that in order to interpret and to predict patterns in biological distribution, it is necessary to understand the physical hydrography.

Organisms within thin layers are several orders of magnitude more abundant than in water immediately above or below the layers. On the basis of abundance alone, layer organisms have been shown to dominate the optical and acoustical signals of the water column.

TRANSITIONS

The data processing software developed for this project has been transitioned for use in autonomous underwater winch profilers with high resolution sensors (physical, optical, biological and chemical) capable of detecting thin layers. The Ocean Response Coastal Analysis System (ORCAS) project was funded by the National Ocean Partnership Program (NOPP). [PI: Dr. Donaghay, Co-PI: Dr. Dekshenieks in partnership with; Wet Labs Inc, SubChem Systems Inc, the Naval Research Laboratory (Stennis), the Naval Oceanographic and Meteorological Command and the EPA]. The autonomous profilers were successfully deployed in conjunction with US NAVY diver visibility exercises in the Gulf of Mexico between 16 and 26 September 2001.

RELATED PROJECTS

- (1) Ocean Response Coastal Analysis System (ORCAS). PI: Dr. Donaghay, Co-PI: Dr. Dekshenieks. Funded by NOPP
- (2) Development of Advanced Technology for Sensing Zooplankton. PI: Dr. Holliday. Funded by ONR code 322
- (3) Plankton Patch Feasibility Experiments. PI: Dr. Donaghay. Funded by ONR code 322
- (4) Finescale Processes in the Plankton: Physical and Biological Linkages. PI: Dr. Cowles. Funded by ONR code 322
- (5) Interactions of Small-Scale Physical Mixing Processes with the Structure, Morphology, Bloom Dynamics and Optics of Non-Spheroid Phytoplankton. PI: Dr. Rines, Co-PI: Dr. Donaghay. Funded by ONR code 322
- (6) Formation of Marine Biological Thin Layers: Recruitment of Zooplankton. PI: Dr. Alldredge, Co-PI: Dr. Case, Dr. MacIntyre. Funded by ONR code 322
- (7) Diurnal Patterns in the Persistence of "Thin-Layers" of Marine Snow, Zooplankton, and Turbulent Microstructure in Coastal Waters. PI: Dr. Alldredge, Co-PI: Dr. MacIntyre. Funded by ONR code 322
- (8) Grazing Processes and the Structure and Persistence of Thin Biological Layers. PI: Dr. Gifford. Funded by ONR code 322
- (9) In-Situ Observation of Irradiance and Time-Dependent Changes in Phytoplankton Absorption Coefficients. PI: Dr. Perry. Funded by ONR code 322
- (10) Physical and Optical Characteristics of Thin Layers. PI: Dr. Zaneveld, Co-PI: Dr. Pegau. Funded by ONR code 322.

REFERENCES

Dekshenieks MM, PL Donaghay, JM Sullivan, JEB Rines, TR Osborn and MS Twardowski. in press. Temporal and spatial occurrence of thin phytoplankton layers in relation to physical processes. Mar. Ecol. Prog. Ser.

Dekshenieks MM, AL Alldredge, A Barnard, E Boss, J Case, TJ Cowles, PL Donaghay, LE Eisner, DJ Gifford, CF Greenlaw, C Herren, DV Holliday, D Johnson, D McGehee, S MacIntyre, TR Osborn, MJ Perry, R Pieper, JEB Rines, DC Smith, JM Sullivan, MK Talbot, MS Twardowski, A Weidemann and JR Zaneveld. in prep: to be submitted October 2001. Changes in Characteristics, Distribution and Persistence of Thin Layers Over a 48-Hour Period.

Redfield AC. 1950. Note on the circulation of a deep estuary: The Juan de Fuca-Georgia Straits. In: Proc Colloquium Flushing of Estuaries. Woods Hole Oceanogr. Inst, Woods Hole, Massachusetts, p. 175-177

Rines JEB, PL Donaghay, MM Dekshenieks, JM Sullivan and MS Twardowski. in press. Thin Layers and Camouflage: Hidden *Pseudo-nitzschia* populations in a fjord in the San Juan Islands, Washington, USA. Mar. Ecol. Prog. Ser.

PUBLICATIONS

Alldredge AL, TJ Cowles, PL Donaghay, DV Holliday, S MacIntyre, JEB Rines, R Zaneveld, JM Sullivan and MM Dekshenieks. in press. Occurrence and mechanism of formation of a dramatic thin layer of marine snow in a shallow Pacific fjord. Mar. Ecol. Prog. Ser.

Dekshenieks, MM, PL Donaghay, JM Sullivan, JEB Rines, TR Osborn, MS Twardowski. in press. Temporal and Spatial Occurrence of Thin Phytoplankton Layers in Relation to Physical Processes. Mar. Ecol. Prog. Ser.

Dekshenieks, MM, TR Osborn, PL Donaghay, JM Sullivan. submitted. The role of local and regional physical forcing for circulation in a coastal fjord: Implications for thin layer distribution. Estuarine Coastal Shelf Sci.

Dekshenieks MM, AL Alldredge, A Barnard, E Boss, J Case, TJ Cowles, PL Donaghay, LE Eisner, DJ Gifford, CF Greenlaw, C Herren, DV Holliday, D Johnson, D McGehee, S MacIntyre, TR Osborn, MJ Perry, R Pieper, JEB Rines, DC Smith, JM Sullivan, MK Talbot, MS Twardowski, A Weidemann and JR Zaneveld. in prep: to be submitted October 2001. Changes in Characteristics, Distribution and Persistence of Thin Layers Over a 48-Hour Period.

Rines, JEB, PL Donaghay, MM Dekshenieks, JM Sullivan, MS Twardowski. in press. Thin Layers and Camouflage: Hidden *Pseudo-nitzschia* populations in a fjord in the San Juan Islands, Washington, USA. Mar. Ecol. Prog. Ser.